HNU-EBL: A Software Toolkit for Electron Beam Lithography Simulation and Optimization

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Background

Electron Beam Lithography

Raith GmbH

IMS Nanofabrication GmbH

direct-write patterning

EUV mask fabrication

https://news.hnu.edu.cn/info/1102/21491.htm
Background

(1) proximity effect, (2) fogging effect, (3) loading effect, (4) charging effect, …
Background

Energy deposition w/o PEC

Energy deposition with PEC

Layout

EBL pattern w/o PEC

EBL pattern with PEC

$\tau$: Development threshold

D: energy density absorbed

H: development results

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Background

“Export Control” to P. R. China
by 《Wassenaar Arrangement》:
https://www.wassenaar.org/control-lists/


3. D. 3. 'Computational lithography' "software" specially designed for the "development" of patterns on EUV-lithography masks or reticles.

3. B. 1. f. 3. Equipment specially designed for mask making having all of the following:

a. A deflected focused electron beam, ion beam or "laser" beam; and

b. Having any of the following:

1. A full-width half-maximum (FWHM) spot size smaller than 65 nm and an image placement less than 17 nm (mean +3sigma); or
2. Not used since 2015
3. A second-layer overlay error of less than 23 nm (mean + 3 sigma) on the mask;

Destination Control Statement

The technology used in Sentaurus Lithography is strictly controlled for export (under Export Classification Number 3D003).

You may not transfer the product or any technical information about the product, or make it available to anyone else, unless you have verified that it is permitted by export laws.

The product may not be exported or re-exported to China, Russia, Armenia, or Vietnam, as well as many other countries, without a valid export license issued by a government agency. Foreign nationals of these and other countries are restricted from receiving this technology unless they are documented permanent residents of countries where export is permitted.

“Export Control” to P. R. China
by U.S. federal government:
https://www.govinfo.gov/content/pkg/FR-2020-10-05/pdf/2020-18334.pdf
Software Toolkit – HNU-EBL

Developed from scratch at Hunan University in China

≈45,000 lines of C++/Python codes
# HNU-EBL: A Software Toolkit for Electron Beam Lithography Simulation and Optimization (by HuNan University)

## Edit material:
- Type and number of chemical elements
- Mass Density

## New Project:
- Resist and Substrate
- Beam energy
- Beam diameter
- Number of electrons

## #1 Monte Carlo:
- MC result
- Gaussian function model
- Grid size on EBL pattern
- GDSII file
- Output file path (only PEC)

## #2 ElectronTrajectories:
- Show different layers of material

## #3 PSF:
- The coefficients of the Gaussian function
- Change the coefficient and redraw the PSF curve
- View the part of the fitted curve
- Linear and log Gaussian fitting curves

## #4 Energy Deposition:
- View diagrams of different structures or different layers
- X-directional or Y-directional section

## #5 dose correction:
- View EPE value and diagrams of different structures or different layers
- Scaling and panning the diagram

## #6 EPE:
- View diagrams of different structures or different layers

## #7 GDSII Visualization:
- Show layout dose
- View layout of different structures or different layers
- Scaling and panning the layout
- Display information of layout
  (Supported Elements: Boundary, Path, Circle, Sref, Aref, Text)

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Demonstration

Step 1. electron scattering & trajectories

Features:
- Arbitrary # of layers
- Arbitrary chemical elements & composition
Demonstration

Step 1. electron scattering & trajectories

Features:
- Monte Carlo based on Rutherford, Mott, etc.
- Point Spread Function curve fitting
Demonstration

\[ E(r) = K \int \int P(r, r') d(r') d^2 r' \]

\[ P(r, r') = \frac{1}{\pi(1+\eta)} \left[ \frac{1}{\alpha^2} \exp \left( -\frac{r^2}{\alpha^2} \right) + \frac{\eta}{\beta^2} \exp \left( -\frac{r^2}{\beta^2} \right) \right] \]

Features:
- CD down to 1.0 nm
- Efficient codes (FFT, FMM, parallelization)

Step 2. dose correction & EPE evaluation
Demonstration

Step 2. dose correction & EPE evaluation

Edge Placement Error (EPE)

Demonstration

Step 3. visualization & inspection (GDSII)

Features:
- GUI-based visualization
- Interfaces to standard formats GDSII files
Verification – Accuracy

5G high-freq filter
Surface Acoustic Wave

PEC: Proximity Effect Correction

Surface acoustic wave (SAW) device

Raith 150 Two EBL machine
Verification – Efficiency

- Same computer – Intel(R) Core (TM) i5 CPU (2.40 GHz), 16GB RAM
- Same calculation layout – M gratings with a size of 1μm×50nm
- Same calculation grid – max calculation with $N=10^8$ pixels

Comparison of PEC calculation time between HNU-EBL & NanoPECS
R&D Team of HNU-EBL

Role:
- Software Development
- Experimental Verification

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Wenze Yao
Chengyang Hou
Hongcheng Xu
Huo Liu
Yiqin Chen
Huigao Duan
Jie Liu
Conclusion

➢ GUI-based EDA with 45,000 lines of C++, Python codes for EBL (EUV/optical mask)
➢ IP by Hunan University (4 patents + 4 software copyrights)
➢ Free license to academia/industry users in any country

Limitations:
➢ Version: first-release (under improvement)
➢ Functionalities: dose-based, 2D correction
➢ Verification: limited experimental verification
➢ ……
HNU-EBL: A Software Toolkit for Electron Beam Lithography Simulation and Optimization (by Hunan University)

http://www.ebeam.com.cn

- IP: 4 patents + 4 software copyrights
- “setup.exe” of GUI-based software
- 70+ pages of software user guide

Free of Charge! License to all EBL Users from Academia/Industry

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